Portland State University
PDXScholar

Geography Faculty Publications and Presentations | Geography

8-2005

Street Trees in the Urban Forest Canopy: Portland, Oregon

Joseph Poracsky
Portland State University

David Banis
Portland State University, dbanis@pdx.edu

STREET TREES IN

THE URBAN FOREST CANOPY:

PORTLAND, OREGON

Project Report

by

Joseph Poracsky, Professor of Geography
&
David Banis, Research Affiliate, CSAR

August 2005

Center for Spatial Analysis and Research (CSAR)
Geography Department
Portland State University
Portland, OR 97207-0751

503/725-3916 www.geog.pdx.edu maps@pdx.edu

This document available as a PDF from the above web site.

Contents

ACKNOWLEDGMENTS

SUMMARY

Trees in the Urban Environment 1

Tree Canopy and Street Trees 2

The Portland Landscape 5

Methodology 8
- Step 1: Preparing an Urban Land Environments (ULE) map 8
- Step 2: Selecting sample patches 9
- Step 3: Visually interpreting street trees 11
- Step 4: Assessing visual interpretation accuracy 13
- Step 5: Digitally interpreting total canopy 14
- Step 6: Assessing accuracy of the digital interpretation 17
- Step 7: Calculating street tree contribution to canopy 21
- Step 8: Identifying patterns and generalizing results 23

Results 27

Concluding Comments 28

REFERENCES 30

Appendix 1: Image Data Tile Information

Appendix 2: Data

Appendix 3: Remote Sensing Issues

StreetTrees-27

ACKNOWLEDGMENTS

This study was made possible by a grant from the Urban and Community Forestry Program of the Oregon Department of Forestry, administered by Paul Ries, Urban and Community Forestry Program Manager. We greatly appreciate Paul's assistance in the implementation and completion of this work.

Thanks go to Wayne Larimer, (B.S. Geography, Portland State University, 2005) for preparation of the shaded relief map of Portland.

Invaluable inspiration during the many hours of writing was provided by:

T. G. Albinoni
C. P. E. Bach
J. S. Bach
L. Boccherini
D. Buxtehude
J. Desprez
F. Danzi
J. Haydn
B. Joel
W. A. Mozart
A. Vivaldi

SUMMARY

Attempts to identify the contribution of street trees to the overall urban forest of a city have been rare and lack consensus on how to measure that contribution – percentage of trees, percentage of canopy cover, or percentage of leaf area. The actual numeric values presented in the literature also vary over a broad range and often are based on estimates, extrapolations from aggregated data, or simply stated with no empirical data referenced. This study was undertaken to evaluate the contribution of street trees to canopy in Portland, Oregon. The study involved both visual and digital analysis of multi-band aerial images, field observation, and GIS analysis involving several ancillary data themes. The strategy was to calculate the street tree component (STC) of the urban forest canopy within a sample of areas in the city and generalize that pattern to the whole city.

The analysis indicates that street trees constitute 3.4% of the whole study area. In commercial / industrial areas the value drops to only 1.1% and in residential areas rises to 4.8%. For the overall study area the STC of the canopy is 17.2%, a value in the middle of the range of values found in the published literature. In commercial / industrial areas we found a value of 23.7% and a value of 16.6% for residential areas.

Residential areas are overall better treed than commercial / industrial areas, but do not rely on street trees to contribute as large a percentage to overall canopy as do commercial / industrial areas. Available planting space in the right-of-way (ROW) is much more nearly constant (or independent of land cover) than the amount of planting space available inside a block. Therefore, the STC tends to vary inversely with the total amount of vegetated area. As the vegetated (read, plantable) area decreases, the ROW becomes a more significant space for planting and the STC increases. Conversely, as the vegetated area increases, the ROW becomes a less significant space for planting and the STC decreases.

For both residential and commercial / industrial areas, the percentage of street tree area within the total canopy varies from locale to locale. The relatively small sampling used in this study suggests that neighborhood age and physical characteristics influence the STC in a given neighborhood, particularly for residential areas. Analysis allowed division of the study area into five residential neighborhood groups that attempt to reflect local differences. A larger / more detailed sampling would allow for improved delineation, perhaps below the level of neighborhood. Three generalized spatial patterns emerge for Portland.

1. Street tree canopy as a percent of area seems to follow an east-west gradient, with lower values to the east and higher values to the west.
2. Street trees as a component of the total canopy takes on an inverted-U shape, with higher values in the Inner Eastside and lower values to the east and to the west.
3. The overall tree canopy category takes on just the opposite pattern – a standard-U – with lower values in the Inner Eastside and higher values to the east and west.

This study represents a useful starting point for understanding the dynamics of an important and highly visible component of the urban forest.

Trees in the Urban Environment

The past several decades have seen an increased recognition and appreciation of the roles played by trees in the urban environment. Research has shown that trees provide a wide variety of aesthetic, ecological, economic, social and human health benefits, ranging from traffic calming, to providing wildlife habitat, to reduction of runoff, to creation of neighborhood pride and improved property resale value. Extended discussions of these and other urban tree values may be found in a variety of sources (e.g., Ebenreck 1989; Miller 1997). Here we will simply note that there are many positive values to trees and these values serve to make a strong case for proactive management of urban trees.

In order to make intelligent decisions regarding tree management, urban forest researchers and managers need to have data on such items as numbers of trees, species composition, age profiles, health conditions, and maintenance needs. Data on counts and characteristics are most useful when they include locations that allow them to be presented in map form. The map format is invaluable in helping to identify spatial patterns and to point to *where* management attention should be directed.

In collecting spatial data about the urban forest, two distinct approaches are used – inventory and mapping of the trees as *individual point features* and mapping the extent of the aggregated tree crowns or *tree canopy*. Enumerating individual trees and their locations produces a wealth of detailed data, but requires a high cost of time and effort. While the increasing availability of digital tools that make the process easier and faster to complete has led to having inventories performed more often, point-based inventories of trees are still not widely-performed. And, since the cost of inventorying individual trees is directly proportional to the number of trees and the area covered, when individual tree inventories *are* performed, they usually cover only limited areas, such as a neighborhood or a small community.

In contrast to tree inventory, tree canopy mapping produces less-detailed data. This is done by not considering individual trees but viewing groups of trees in the aggregate as an interwoven surface of branches and leaves. Mapping can be completed more quickly and at less expense than tree inventory by using aerial or satellite imagery and established techniques in remote sensing data analysis. Canopy mapping has been used for areas the size of cities or regions (Rowntree 1984; Newman 1997; Iverson and Cook 2001). It offers a more economical approach than mapping tree locations, especially for large areas, where the synoptic view provided by the canopy extent map can provide assistance in making strategic management decisions.

Since they provide different kinds of information, the choice between an inventory and a canopy mapping obviously depends on the types of information desired, as well as cost and time constraints. Since funds for urban forestry programs are usually very limited, canopy mapping is usually more practical to perform than a tree inventory. Not only is a canopy mapping less expensive and more quickly produced, but it can provide overview data that is invaluable in facilitating the planning and implementation of an inventory.

Tree Canopy and Street Trees

A recent study of tree canopy in Portland, Oregon over the period 1972-2002 employed satellite imagery at a 25 meter resolution to map differences in canopy density and to identify a recommended canopy cover target level for tree planting projects (Poracsky and Lackner 2003). The study segmented the city into four of the urban land environments (ULEs) identified in the City's *Urban Forest Management Plan*. While nominally based on land uses, the ULE categories are intended to recognize that different land uses offer different sets of constraints on, and opportunities for, tree planting. As a consequence, different ULEs are likely to be associated with different canopy cover percentages.

The canopy study made recommendations for target canopy cover in two ULEs – residential and commercial / industrial. No recommendation was made for the ULE of right-of-way (ROW) street trees – plantings along the streetside – since the narrowness of the street right-of-way makes it impossible for medium resolution satellite data to separate out the street trees from adjacent trees in other ULEs in which they are embedded.

Although the canopy study did not address the street tree issue, it was recognized that street trees are an important component of the urban forest. One reason is that the right-of-way environment is where regulatory forestry programs normally have jurisdiction and can therefore directly impact tree management. A second reason for the importance of street trees is their location along the streetscape. Given their size and prominent location between street and sidewalk on the everyday routes along which urban residents live and travel, street trees are the most highly visible component of the urban forest.

From a canopy cover analysis viewpoint, an important question for urban tree management is, "What is the street tree component (STC) of the urban forest?" A second related question is "Does the STC vary over the whole canopy and, if so, what kind of variation pattern is exhibited?" In an initial attempt to answer these questions, a brief review of the urban forestry literature was undertaken. Four conclusions emerged from the review.

First, while there are a number of canopy mapping studies, there have not been a great number of attempts documented in the literature to identify the contribution of street trees to the total urban forest. A total of six references were identified, and these are summarized in Figure 1.

Second, the literature reflects variability in the approach to evaluating street trees as a component of the urban forest. Sometimes what is reported are percentages based on counts of trees (Moll 1989) and at other times percentages based on canopy cover (Grey and Deneke 1986). Sometimes two figures are presented, one for percentages of trees and one for canopy area. For example, McPherson, Nowak and Rowntree (1994) report that 10% of the trees (by count) in Chicago are street trees, but also note that the street trees constitute 24% of the leaf area (a canopy measure that incorporates the third dimension component of tree height).

Third, the actual numeric values presented in the literature vary over a broad range. For example, while McPherson, Nowak and Rowntree (1994) report that 10% of the trees in Chicago are street trees, they report a much smaller figure of 2.7% for suburban Cook County. In 1989 Moll (16) cites a figure of 33% for cities in general, but four years later (1993) reports a figure of 10%. In neither case does he cite an empirical study. It is possible, and perhaps likely, that, rather than representing discrepancies, this wide range of numbers (2.7% - 33%) represents real differences that result from variations in defining individual study area criteria, differences in the level of development of study areas, and variation in local environmental conditions.

Fourth, there is often a reliance in the literature on "estimates" and calculations from aggregated data. For example, Moll (1989 16) says "about 1/3 of the trees within the city limits are street trees" without citing any specific studies. Grey and Deneke (1986 17) present a figure of 30% for "trees in urban areas [that] are publicly owned" but that figure must be reduced an unknown amount for street trees, since the publicly owned land category includes parks, railroad rights-of-way, and public buildings and grounds. In 1999 McPherson et al found 21.4% of the canopy of Modesto, CA was composed of street trees. (This figure was not presented directly, but was derived by calculation from other figures presented in the study.)

What can we conclude based on the four points drawn from this brief literature review? Simply stated, there is no consensus either in terms of definition or numerical value as to what street trees contribute to the urban forest canopy. In fact, there is strong indication that a moderately wide range of values – not a single universal value – may be the rule, the

Percent		Source	Comments
Trees	Area		
<30	-	Grey and Deneke 1986 17	Estimate of trees in urban areas that are publicly owned is 30%; minus parks, public buildings and
33	-	Moll 1989 16	"about 1/3 of the trees within the city limits are street trees"
10	-	Moll and Kollin 1993 (quoted in Miller 1997 31)	10% of urban trees are on publicly owned land
10.1	-	Nowak 1994 13	City of Chicago
-	24	Nowak 1994 13	City of Chicago – leaf area (not canopy)
2.7	-	Nowak 1994 13	Suburban Cook County
-	9.5	Nowak 1994 13	Suburban Cook County – leaf area (not canopy)
-	10	American Forests 1997	Source not physically viewed; cited on website (www.edc.uri.edu/personal/greg/atlas/) August 2,
-	21.4	McPherson et al 1999 241	Figure not cited directly in the article; calculated by authors from other figures presented in the article.

Figure 1. Summary of literature on percent of urban forest canopy that is street trees. Six citations were found that listed numbers, though one (Nowak 1994) listed multiple values, as described in the "Comments;" each of these values is listed separately in the table. (Source: complied by authors from cited sources.)

actual number depending on the characteristics of the area of concern. It may not be possible to transfer street tree canopy values from one area and apply them to another. Understanding a particular area is likely to require a local study.

Based on these conclusions, this study was undertaken with the intention to: (1) evaluate the contribution of street trees to canopy in Portland, Oregon; (2) identify possible spatial patterns associated with the street contribution; and (3) explore some of the factors that might help explain the pattern. Isolating the issue of street trees as a factor separate from the rest of the urban canopy can improve our understanding of how urban forest processes operate. The results will help identify differences between segments of the city, and can be helpful in performing comparative studies between Portland and other cities.

The Portland Landscape

The City of Portland lies at the confluence of the Columbia and Willamette Rivers (Figure 2). The Columbia River forms the northern boundary of the city, while the Willamette River flows through the city and marks a distinctive border between two very different parts of the city.

Most of the city landscape west of the Willamette River is a system of steep-sided hills that rise 500 to 1,000 feet above the narrow strip of river flood plain adjacent to the river. The West Hills are heavily forested with a mix of native trees dominated by second-growth bigleaf maple, Douglas-fir, and alder. The flat lands below are heavily developed and have a much less dense canopy. The pattern of development on the low-lying areas may be divided into four roughly equivalent-sized zones. The northern two-quarters is predominantly industrial land, the next one-quarter south includes the historic downtown / central business district, and the southernmost one-quarter is largely industrial and commercial.

Land on the east side of the river is generally flat to slightly rolling, except for several remnants of isolated volcanic buttes. Much of the Eastside along the south shore of the Columbia River is industrial, as is most of the area on the east bank of the Willamette, together creating a swath of commercial / industrial land adjacent to the rivers that takes on the general shape of a northwesterly-pointing "V" (Figure 3). The width of the industrial-V varies and engulfs the largely residential area of the Eastside that is home to the majority of Portland's population. Throughout the residential area are small pockets and strips of commercial development, the most prominent being the Lloyd District, a high-rise development that represents the leap-frogging of the downtown across the river from its

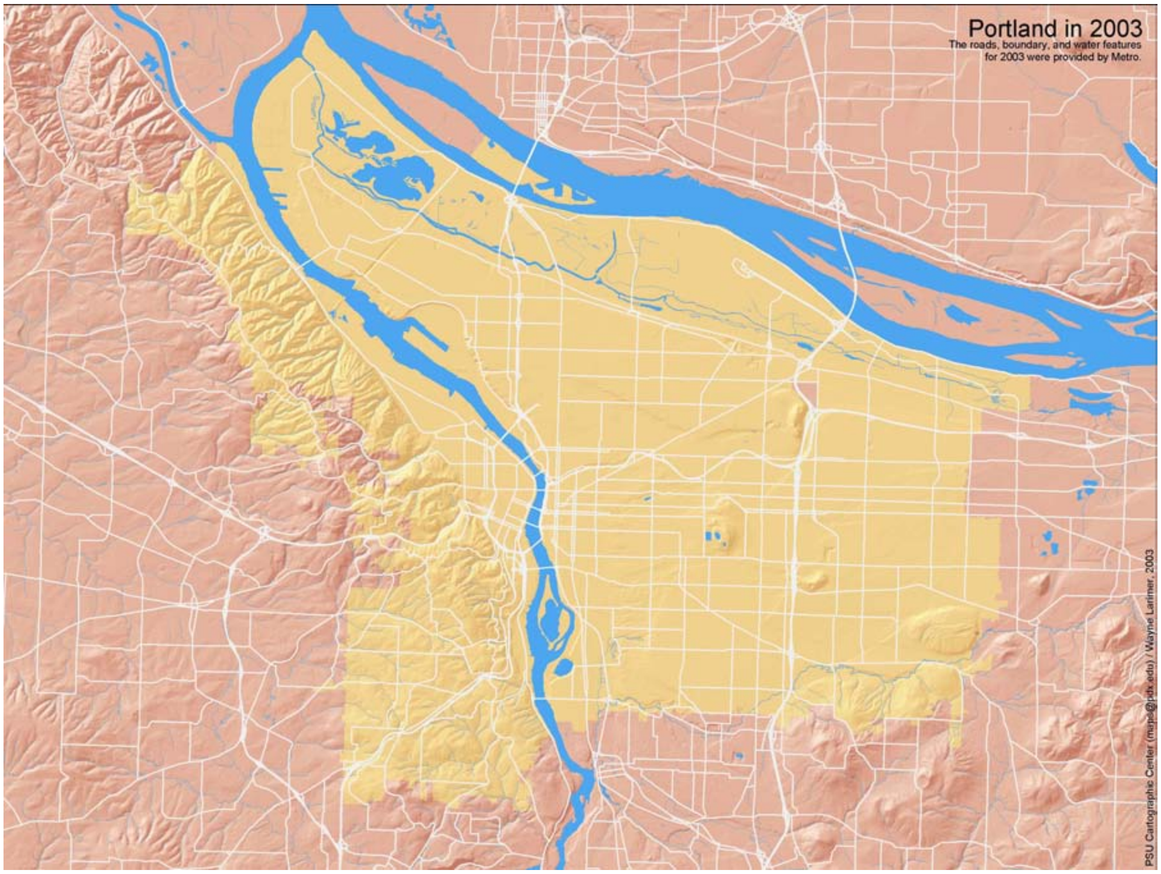

Figure 2. The City of Portland has two distinct physical characteristics that are illustrated by this map. First is its *situation* at the confluence of the Columbia and Willamette Rivers. The Columbia River forms the northern boundary of the city, while the Willamette River flows through the city dividing it into two distinct, though unequal-sized, portions.

This division is echoed by the City's second critical physical characteristic, its *site* character relative to topography. The area west of the Willamette River is dominated by a north-northwest trending linear system of hills rising steeply about 1,000 feet above the narrow, heavily-developed river terrace. The east side of the river is flat to slightly rolling, but punctuated by several remnant volcanic buttes. (Map by Wayne Larimer.)

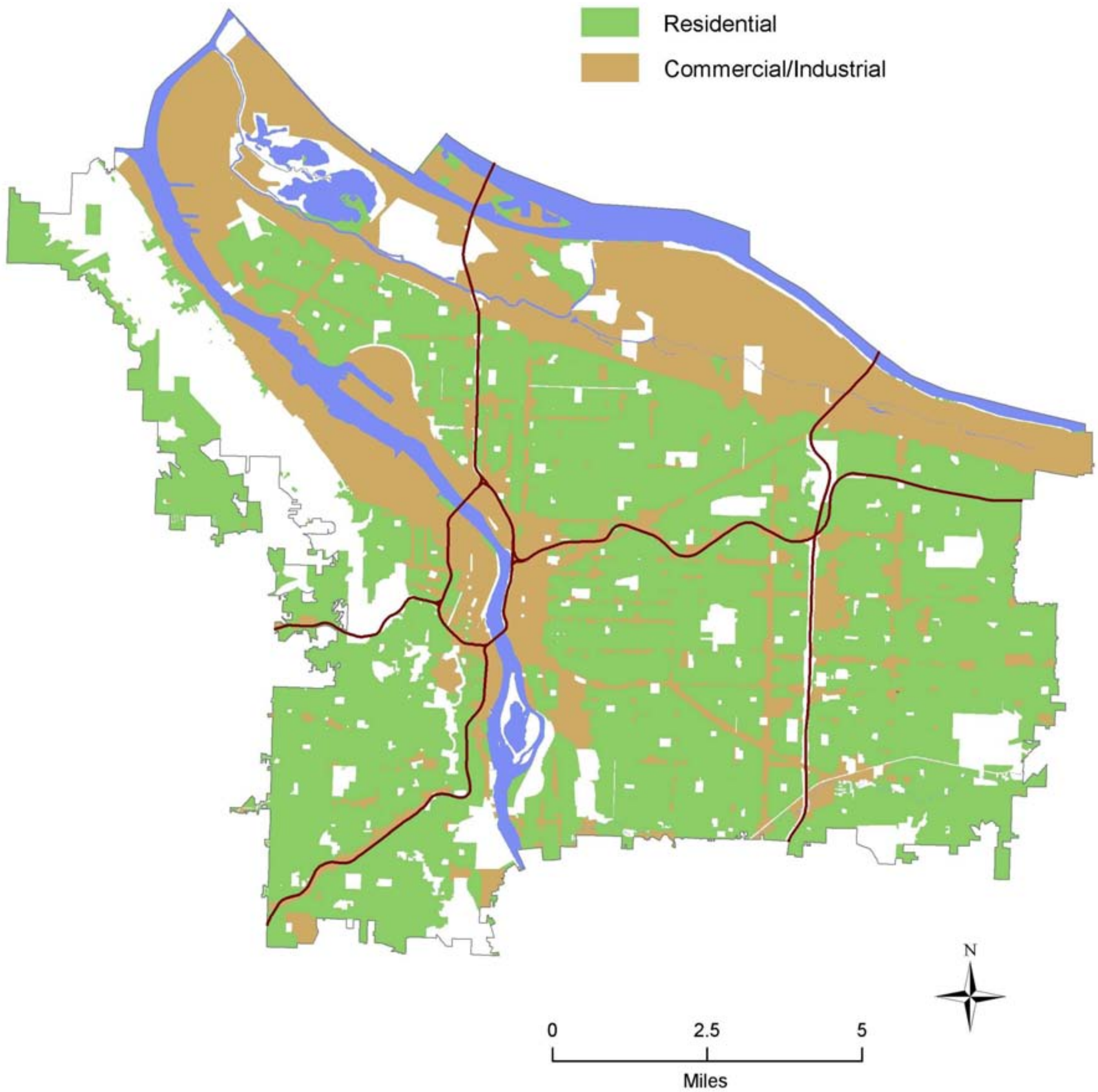

Figure 3. The study area examined in this report is portrayed in color to indicate the associated urban land environment. Only residential and commercial / industrial areas were examined. The study area thus consists of the City of Portland minus areas in parks, rights-of-way associated with Interstate highways, and rivers within the city limits – a total of 77% of the city area. Note the northwesterly-pointing "V" of commercial / industrial land adjacent to the rivers.

confining historic location west of the Willamette.

The pattern of relief in the city – with the linear feature of the West Hills dominating the western portion, and the smaller but visually prominent isolated hills on the east side – plays a potentially important role in the pattern of tree canopy over the city. Much of the densest canopy in the city is found on the steeper, landslide-prone, and therefore more difficult to develop parcels of the West Hills. In contrast, the buttes to the east have more stable slopes and are being rapidly developed as view-home properties, thus losing their previous dense tree cover.

Methodology

The basic methodology of this study involved calculating the street tree component (STC) within a sample of small areas throughout the city, identifying a generalized pattern in the results, and considering explanations for the pattern. The processes involved included visual image interpretation, digital image analysis, field observation, development of several GIS layers, mapping and statistical tabulation of data. Image processing and GIS analysis was performed using Idrisi Kilimanjaro software and ArcGis was employed for map composition. The methodology is discussed here in the text as eight major steps:

1. Preparing an Urban Land Environments map
2. Selecting sample patches
3. Visually interpreting street trees
4. Assessing the visual interpretation accuracy
5. Digitally interpreting total canopy of the city
6. Assessing accuracy of the digital interpretation
7. Calculating street tree contribution to canopy
8. Identifying patterns and generalizing results

Step 1: Preparing an Urban Land Environments (ULE) map

Metro, the regional government for the Portland area, provides basic land use data through its Regional Land Information System (RLIS). The classifications of land in their data base were used to delineate ULEs for this study. Two ULEs were evaluated in this study – residential, constituting 51.5% of the city, and commercial/industrial, constituting 25.5% of the city. We expected that the percentage of street trees comprising the canopy within these two classes would be substantially different. Land that was part of the parks ULE and the natural areas ULE was not considered in the analysis, nor were several broad strips of right-of-way associated with the Interstate highways. Together with portions of the rivers within city limits, these excluded areas constituted 23% of the city's physical area. Figure 3 portrays the portions of the city actually included in the study.

Step 2: Selecting sample patches

The narrow linear character of street tree plantings means that they are not distinguishable at the moderate-to-coarse spatial resolution of scanning systems such as the Landsat MSS and Thematic Mapper. To obtain the higher resolution that was called for, one-meter resolution digital aerial camera images of the city, acquired in June of 2002 by the City of Portland Bureau of Environmental Services, became the basis for the study. Three bands – green, red, and near infrared – were used for the analysis.

At one-meter resolution, the remote sensing imagery constituted a large data set, which necessitated a sampling approach to the analysis. A sample patch size of 200 meters x 200 meters (40,000 pixels) was decided on. This area represents about 5-7 blocks, depending on the block size in the neighborhood. A grid of 200 meter squares was overlaid on the digital data and 200 random sample patches selected. (See Appendix 1 for a discussion of digital image size issues.)

The sample patches were then overlaid with the ULE delineations and those patches that included just residential land were retained to constitute the residential area sample. For commercial areas a somewhat different approach was used. Most commercial strips are too narrow to completely fill the sample patch size of a 200 meter x 200 meter square. Accordingly, an allowance was made to keep samples in which the patch included a large proportion of a commercial strip. In these instances only the commercial portion of the sample patch was considered and included in the analysis, making those patches smaller than the 200 meter x 200 meter size. Any sample patches that fell outside the City limits, within parks, in water, or were split by large highways or freeways, were eliminated from the sample.

The final result was a total of 62 sample patches – 37 residential areas and 25 commercial / industrial areas – that fit the sampling criteria. The distribution of sample patches by neighborhood is portrayed in Figure 4. The total area included in the 62 sample patches comprised about 0.5% of the study area. These sample patches constituted the foundation for the visual interpretation and analysis. (Appendix 2 contains the sample data.)

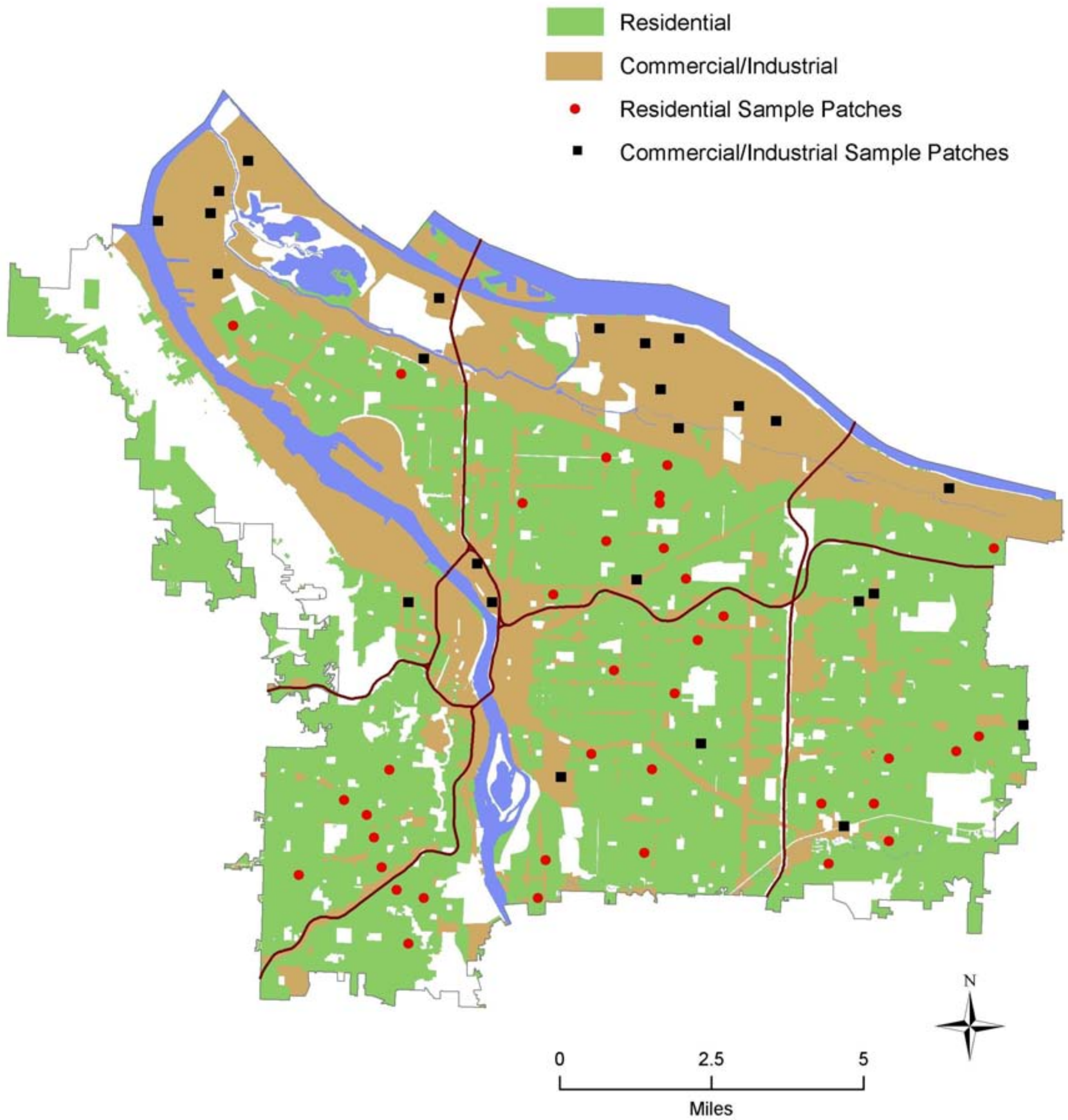

Figure 4. The 62 sample patches used to visually interpret and digitize canopy cover. Patches represent 200 meters x 200 meters on the ground but are shown here at an exaggerated size for legibility.

Step 3: Visually interpreting street trees

The canopy for street trees was interpreted visually from false color composite displays on the computer screen and digitized as polygons. Figure 5 portrays two examples of the results of the visual interpretation process. This visual interpretation of street tree canopy was later used in conjunction with data on the total area covered by tree canopy to calculate the STC – the percentage of total canopy area that is represented by street tree canopy – for each of the 62 sample patches.

Distinguishing vegetation from non-vegetation areas is a generally straightforward visual interpretation process when using color infrared data. Likewise, trees can usually be separated from grass by a combination of tone and texture. However, when attempting to distinguish street trees as a sub-class of woody vegetation there are several persistent conditions that introduce subjectivity into the interpretation. First, there is no clear spectral division that separates what is a shrub or bush from what is a tree. In general, trees can be distinguished from large bushes by shape and from small bushes by shadows, but these shape and size clues are not always conclusive.

A second problem is that shadows cast by the trees obscure edges and can make outlining the exact canopy boundary difficult. This condition is especially vexing for large trees, which cast broad shadows: the edge of the tree is somewhere in the shadow but, depending on the shape / form of the tree, the shadow may be mostly on the ground or mostly on the tree, or somewhere in between. In such cases the interpreter can do nothing but make their best subjective determination.

A third problem is that there are areas where the canopies of street trees and yard trees have grown together and are continuous. Here it is sometimes difficult to discern that the canopy includes both street and yard trees, and, in instances where it is clear that both occur, it is sometimes difficult to identify where to separate the two. None of these three problems is overwhelming, but together they serve to complicate the interpretation process and introduce a potential source of error.

In industrial areas, the generally small amounts of vegetation – both in terms of total area and in terms of the sizes of individual canopy patches – works to make the visual identification of street trees easier. The same holds true for commercial strips, where street trees tend to be the largest segment of what is usually a small amount of vegetation. Most plantings in both commercial and industrial areas are in orderly rows, making identification easier by bringing in the added visual clue of pattern. Of particular help in commercial and

Figure 5. Examples of image interpretation of street trees in two different residential neighborhoods of Portland. Each white box represents a 200 meter x 200 meter square sample patch within which street trees were delineated. For each sample patch the total area of delineated street trees was then calculated.

industrial areas is the frequently high proportion of impervious surface, which provides a spectral background against which trees strongly contrast.

For residential areas, the ease with which right-of-way areas and associated street trees could be distinguished from all other non-street trees varied by neighborhood. In this regard, the presence or absence of sidewalks was the most important factor. Three geographically distinct types of residential area could be identified, and each provided its own unique challenges during the interpretation process. First, the North Portland and the Inner Eastside neighborhoods have a conventional grid layout and sidewalks. Here, there was little confusion between street trees and yard trees. The challenge in these neighborhoods was the substantial numbers of small street trees that were difficult to detect on the imagery.

The second type of residential area was found in Southwest Portland. This area is still heavily forested, even in developed portions with many winding streets and few sidewalks. In these neighborhoods, it could be difficult to distinguish between street and yard trees.

The third type of residential area was found in the Outer Eastside of Portland. Here there is a conventional grid layout, but frequently no sidewalks and a higher proportion of undeveloped properties than the Inner Eastside. The right-of-way can be difficult to define, and distinguishing street trees from yard trees could be difficult.

Despite the subjectivity introduced by these persistent conditions, the visual interpretation process proceeded smoothly and was completed with a high degree of confidence.

Step 4: Assessing visual interpretation accuracy

The accuracy of the visual interpretation method was checked by conducting an on-the-ground tree inventory for 12 of the 62 sample patches. A total of four commercial / industrial and eight residential patches were selected, providing data on 349 residential street trees and 133 commercial / industrial street trees.

Two sources of error were identified. First, even with the high resolution imagery, some young or columnar street trees were too small to be identified. In some sample areas, these small trees were as much as one third of the count of street trees. The accuracy assessment indicated that the visual interpretation process missed 21% of the total count of trees that were observed in the field. Note that this error rate refers to individual trees, not canopy. Partially mitigating this problem is the fact that these trees are so small that, even in total, they comprise a very small percentage of the total canopy cover. Thus, this 21% missed tree figure does not imply a 21% canopy area error.

The second source of error was occasional confusion between street trees and yard or private property trees. This number varied by type of neighborhood, with a 76% accuracy rate in neighborhoods without sidewalks and an 87% accuracy rate in neighborhoods with sidewalks. This problem was most common in Southwest Portland and the Outer Eastside, both areas having many streets without sidewalks.

Additional analysis of the accuracy of the visual interpretation is provided by examining the accuracies with regard to ULE. Figure 6 presents a graphic portrayal that assists in understanding this analysis. For residential areas, 79% of the street trees observed in the field were identified by the interpretation. And, of all the residential area trees that were identified by the interpretation as street trees, 83% were correctly identified as street trees. In commercial / industrial areas, 90% of the street trees observed in the field were identified by the interpretation. And, of all the commercial / industrial area trees that were identified by the interpretation as street trees, 92% were correctly identified.

These accuracy figures are conservative, since they are based on counts of trees, not extent of canopy, and almost all the street trees that were missed or misidentified were small. As would be expected from raster sampling theory, the threshold for being able to detect small trees was about 2 meters x 2 meters, or four times the area of the pixel. Trees below this size were frequently not distinguishable on the one-meter pixel images.

Figure 7 presents the accuracy data in tabular form and makes the case that the visual interpretation likely results in a slight overestimation of the amount of street tree canopy. The actual amount of likely overestimation is unknown, but is likely to be in the range of 3 to 6%.

Step 5: Digitally interpreting total canopy

The next step was to perform a digital interpretation of the one-meter digital data and produce a map of land cover types. The necessity to use high resolution data is well recognized in the remote sensing literature. Jensen and Cowen (1999) note that high resolution imagery is required in order to effectively study particular urban attributes. However, due to the relatively recent availability of high resolution digital imagery, urban land use classification with high resolution digital imagery has not been done a great deal

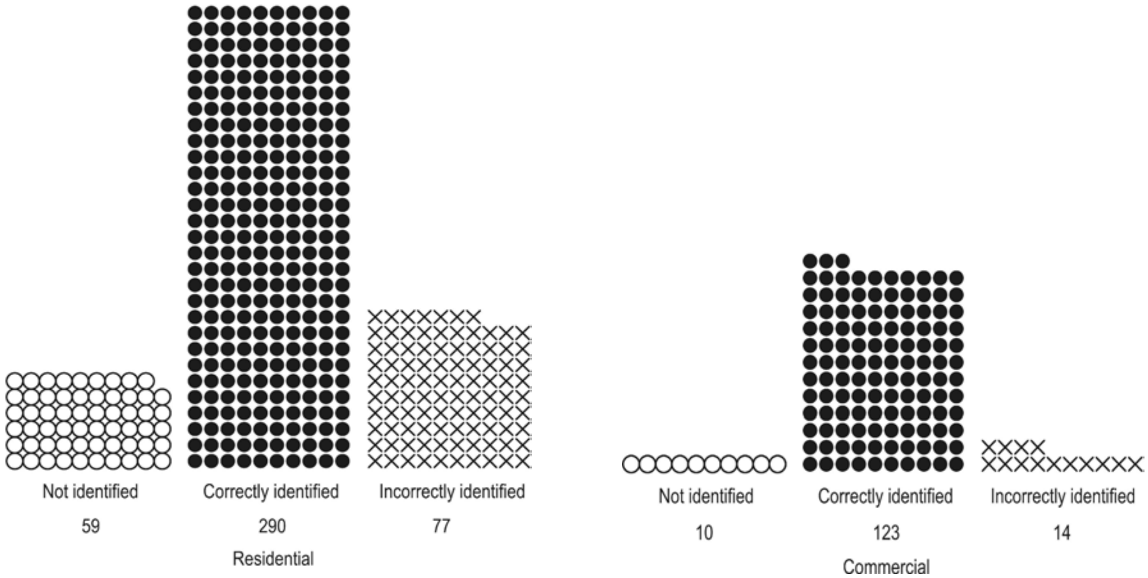

Figure 6. Accuracy of the visual interpretation of street trees as compared with field observations. Black circles represent street trees that were correctly identified through visual interpretation. Open circles represent street trees that were missed / not identified through visual interpretation. The x's represent non-street trees that were incorrectly identified through visual interpretation as street trees.

In residential areas, the visual interpretation correctly identified 83% (290/349) of the street trees observed on the ground. The visual interpretation failed to identify 17% (59/349) of the street trees. Of those trees that the visual interpretation identified as street trees, 79% (290/367) actually were, producing an incorrect identification in 21% (77/367) of the cases.

In commercial / industrial areas, the visual interpretation correctly identified 92% (123/133) of the street trees observed on the ground. The visual interpretation failed to identify 8% (10/133) of the street trees. Of those trees that the visual interpretation identified as street trees, 90% (123/137) actually were, producing an incorrect identification in 10% (14/137) of the cases.

Note that these figures refer to *counts of trees*, not *canopy area*. Many of the errors involve small trees that, in the aggregate, do not constitute a large portion of the canopy.

	Residential	Commercial / Industrial	Combined / Total
# Trees - Total	349	133	482
# Correctly ID'd	290	123	413
% Correctly ID'd	83%	92%	86%
# Omitted / Missed	59	10	69
% Omitted / Missed	17%	8%	14%
#ID'd as Street Trees - Total	367	137	504
# Incorrectly ID'd	77	14	91
% Incorrectly ID'd	21% (77 / 367)	10% (14 / 137)	18% (91 / 504)

Figure 7. Summary of the accuracy and error rates for the visual interpretation of street trees. In both the case of the residential category and the commercial / industrial category there is a higher rate of commission errors (i.e., incorrectly identifying a non-street-tree as a street tree) than omission errors (i.e., failing to identify a street tree).

From this we would conclude that the visual interpretation leads to a slight over-estimation of street tree canopy, since (a) there are more trees incorrectly identified as street trees than there are trees omitted / missed, and (b) the trees that are incorrectly identified are larger and contribute more to canopy than the missed smaller trees.

(Zhang 2001; Myeong et al 2001.) Going to higher resolution imagery introduces some problems that are not obvious beforehand but quickly become apparent once the analysis is undertaken. The critical issues are: (a) the high resolution of the data means there likely are different technical issues to consider compared to using medium resolution imagery; and (b) there is a very limited body of work to rely upon for urban land use classification with high resolution imagery.

To calculate the percentage of street trees, we first performed a digital classification of total canopy for the entire digital data set. If our goal was simply to identify the vegetated areas of the data set, a vegetation index using a ratio of the near infrared band to the red band would likely suffice (Lillesand and Kiefer 2000). However, in order to distinguish between different categories of vegetation a different method was needed. A supervised approach using a minimum distance to means classifier and the near-infrared, red and green bands was employed. A total of 67 training sites were used for the classification. Three land use/cover classes were identified: trees comprised one class, grass and shrubs a second class, and all other land use types (impervious surfaces, water, bare soil) were combined into a third class, here called *non-vegetated surfaces* for convenience. An example of the resulting classification map for a sample patch is shown in Figure 8.

The results of the final classification are summarized in Figure 9. For the whole study area, non-vegetated surfaces predominate with 59% of the area. Breaking this figure into commercial / industrial (76.8%) and residential (48.2%) clearly illustrates the difference in potential tree planting space between these two land covers. And that difference in potential clearly shows up in the tree category where the 29.2% residential tree canopy represents a value 6.2 times the 4.7% of the commercial / industrial category.

Step 6: Assessing accuracy of the digital interpretation

Accuracy assessment relied on a random set of pixels and the use of visual interpretation to determine the "true" identification of each pixel. From that data, an error matrix was prepared and used to calculate the accuracy of the digital classification. The results are presented in Figure 10. The overall accuracy for all of the digitally identified classes is 90%.

With only a single composite class for pavement, buildings, water, and bare soil, it is not surprising that the accuracy for identifying that class is a high value of 96%. It is clear that vegetated features can be very reliably distinguished from non-vegetated (provided they are large enough to be captured by the pixel resolution).

Figure 8. Land cover classification for a sample patch in Northeast Portland. The white box represents a 200 meter x 200 meter square sample patch within which three different land covers were delineated.

	Tree Canopy	Grass/Shrub	Nonveg Surface
Study Area - Residential	29.2	22.6	48.2
Study Area - Commercial/	4.7	18.5	76.8
Study Area - Total	19.9	21.0	59.0

Figure 9. Summary of the digital classification for the whole study area. Note the high percentage of non-vegetated surface in the commercial / industrial areas compared to residential areas – 76.8% versus 48.2% – which represents a 1.6 times difference in the potential for tree planting. This can be compared to the 29.2% versus 4.7% tree canopy cover for residential versus commercial / industrial areas – a 6.2 times difference. When also compared to the figures for grass, it is clear that residential areas exhibit not only a greater area of overall vegetation cover, but also a much higher disposition to plant trees than do commercial industrial areas.

		Visual Interpretation				
		Trees	Grass	Non-Veg	Row Total	**User's Accuracy**
Digital Classification	Trees	53	7	1	61	**87%**
	Grass	6	25	0	31	**81%**
	Non-Veg	3	1	92	96	**96%**
Column Total		62	33	93	188	Overall = 90%

Figure 10. Error matrix for the digital land cover classification. Numbers represent the count of individual pixels examined in each category. The shaded diagonal cells represent agreement between the digital interpretation and the visual interpretation. The User's Accuracy represents the reliability of the digital interpretation performed on the sample of patches, as compared with the visual interpretation. This ranged from 81% for grass, to 87% for trees and a high of 96% for non-vegetated surfaces.

The accuracies of 87% and 81% for trees and grass, respectively, while not as high as for the non-vegetated class, are still good. The error pattern for both of these classes indicates the lowered reliability of distinguishing sub-classes of vegetation. The signatures for trees covered a wide range of values and were occasionally confused with the signature for grass / shrub, which had a much smaller range of values. To a smaller degree there was also some conflation between non-vegetated surfaces and shadow areas of trees, especially for conifers, which are frequently much taller than deciduous trees and cast longer shadows.

Note that there are few firm guidelines on what is an "acceptable" accuracy for a remote sensing problem. One figure frequently quoted in the literature for land use / land cover analysis is 85% (Anderson et al 1976). Using this figure as a standard, the 81-96% range for accuracy in this situation would appear to be acceptable.

Commercial / industrial areas had varying amounts of canopy cover vegetation, but a consistently small percentage of these areas were vegetated and frequently the trees were small and potentially not identified. For two of the sample patches, total tree canopy was determined using the same visual identification and digitization method that was used for street trees. One case was when the total tree canopy was 1-2% of the total number of pixels in the sample patch. The digital interpretation tended to underestimate total tree canopy (due to the shadow problem) for commercial / industrial, where it overestimated total tree canopy for residential (the grass problem is bigger than the shadow problem). The other case where visual interpretation was used was when looking at a commercial strip instead of the entire sample patch. Thus, for the commercial / industrial areas included in the table, it is a combination of the digitally and manually digitized values that are included in the table.

Step 7: Calculating street tree contribution to canopy

Once we had digitally classified the land cover for the study area, we were then able to calculate an estimate of the street tree contribution to canopy. For each of the 62 sample patches the area of the patch delineated as street trees was divided by the area of total tree canopy from the digital land cover analysis. A breakdown of the findings for tree canopy into street trees and non-street trees is presented Figure 11. Four key observations can be made.

1. A total of 3.4% of the study area consists of a land cover of street trees and 16.5% non-street trees. While it is possible to add these two figures to obtain a total for trees of

	Street Trees	Non-Street Trees	All Trees *(Street plus Non-Street)*	**Street Tree Component**
Study Area - Residential	4.8	24.4	29.2	**16.6**
Study Area - Commercial/	1.1	3.6	4.7	**23.7**
Study Area - Total	3.4	16.5	19.9	**17.2**

Figure 11. Percentages of the study area in street trees and non-street-trees. Note that although residential areas have a much higher percentage of overall tree canopy than do commercial / industrial areas (29.2% versus 4.7%), the street tree component of the urban canopy is higher for commercial / industrial areas (23.7%) than for residential (16.6%).

19.9%, it must be remembered that the total figure – like the street tree and non-street tree figures – refers only to the study area of residential and commercial / industrial land, not to the entire city. This study did not include park areas, but if they were added in, the city-wide canopy figure would be higher than 19.9%. It is important that all of these figures be used with caution, and accompanied by a clear description of what they represent.

2. The percentage of the study area that consists of street tree canopy varies with the land cover category. The city-wide figure for commercial / industrial is only 1.1 % and for residential 4.8%. While neither figure is very high, note that there is more than a four times difference between them. Residential area street trees clearly represent a greater portion of the city area than do commercial / industrial area street trees.

3. The percentage of total tree canopy contributed by street trees varies with the land cover category. In residential areas 16.4% (4.8 / 29.2) of tree canopy comes from street trees, while in commercial / industrial areas the figure is 23.4% (1.1 / 4.7). Thus, street trees are proportionally a greater contributor to overall canopy in commercial / industrial areas than in residential areas.

4. The percentage of street trees as part of the total study area canopy cover – 17.2% – is in the middle of the 9.5 to 24% range quoted in the literature.

Step 8: Identifying patterns and generalizing results

Figure 12 presents three different approaches to viewing tree canopy – street trees as a percent of total area, street trees as percent of total canopy, and total canopy as a percent of area. Some notable variation in street trees is seen between different residential areas. The Southwest group of neighborhoods with 6.1% of their area in street trees is the highest, while Outer Southeast with 2.8% is the lowest. The general pattern of tree densities follows an east-west gradient, with lower values to the east and higher values to the west.

Visual examination of the data and field observation experiences led to dividing the residential areas into the five neighborhood groups indicated on Figure 13: Inner Northeast, Inner Southeast, Outer Eastside, Southwest, and Northwest. These divisions closely follow the locally recognized but informal terminology for grouping neighborhoods of the City. Interstate 205 serves generally as the dividing line between Inner and Outer Eastside. The underlying logic of these groupings was to keep individual neighborhoods intact and to group them together based on similar canopy densities. Since they exhibit similar

	Street Trees - Percent of the Area	Street Tree Component (STC) Percent	Street Tree Component (STC) Max-Min Values	Total Tree Canopy Percent	Total Tree Canopy Max-Min Values
Inner NE - Residential	5	22.6	6.8 - 42.8	22.1	12.7 - 30.4
Inner SE - Residential	5	23.2	7.0 - 38.6	21.6	12.1 - 35.4
Outer East - Residential	2.8	10.4	6.4 - 14.6	27.2	10.5 - 49.7
SW - Residential	6.1	12.9	3.0 - 26.8	47.1	21.0 - 61.5
NW - Residential	--	--	--	--	--
Study Area - Residential	4.8	16.6	3.0 - 42.8	29.2	10.5 - 61.5
Study Area - Commercial/	1.1	23.7	0 - 84.3	4.7	0 - 31.1
Study Area - Total	3.4	17.2	--	19.9	--

Figure 12. Three perspectives on tree canopy percentages in residential and commercial / industrial areas of Portland. No values are given for residential in NW because the amount of residential land is small and much of it is a mixed use combination with commercial dominating on the streetscape. In this unique situation it was felt that residential figures would not be meaningful.

The first data column represents street trees as a percentage of total area, characterized by a relatively narrow range of single-digit figures. The second column provides the figures for street trees as a percent of total tree canopy, with a range form 10.4 to 23.7%, depending on the geographical area being considered. The third data column represents total canopy cover in the area, with a very wide range of 4.7 to 47.1%. This column serves as the denominator when calculating street trees as a percentage of the total canopy.

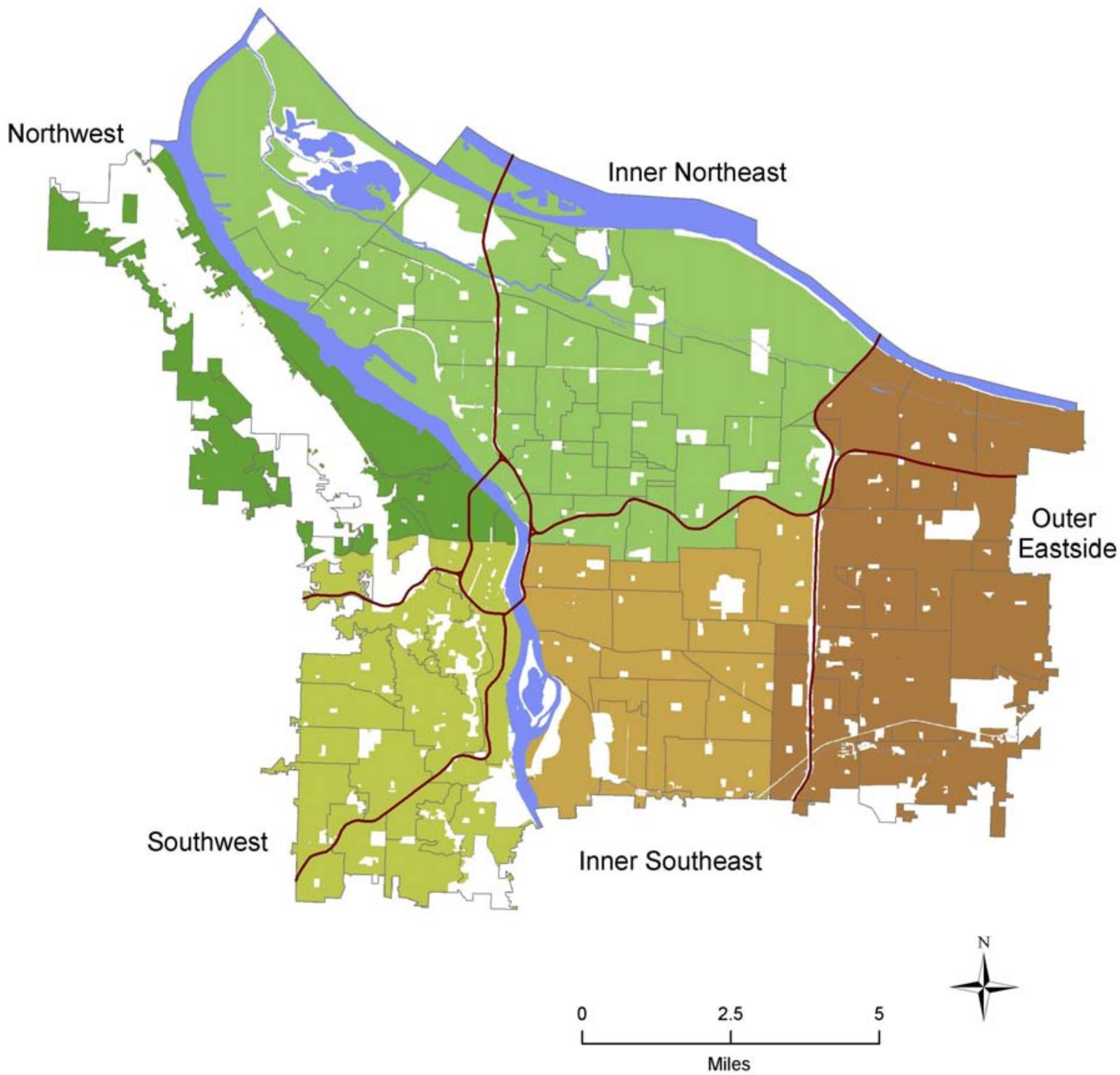

Figure 13. Based on a variety of factors examined during this study, a regionalization was made of Portland's residential areas as five neighborhood groups. The regions closely follow locally recognized, informal terminology for grouping neighborhoods of the City. The underlying logic of these groupings was to keep individual neighborhoods intact and to group them together based on similar canopy densities. The divisions are based primarily on the data examined in this study, but also include both a degree of subjectivity and a degree of generalization. While not definitive, this regionalization provides a useful initial attempt at understanding the pattern of street trees in Portland.

composite Inner Eastside for the sake of discussion. The northwest section of Portland is dominated by Forest Park and industrial areas with relatively small residential clusters, and there were no residential samples from this area.

The Inner Eastside residential areas have the highest street tree contribution to the urban forest canopy – 22.6% in Inner Northeast and 23.2% in Inner Southeast. These areas also exhibited high variation in street tree planting, with some blocks dominated by large street trees and other blocks almost devoid of street trees. Sidewalks typically delineate the right of way, but the width of the right of way is variable. The mean tree canopy itself was fairly consistent and uniform throughout.

The Outer Eastside residential areas have the lowest street tree contribution to the urban forest canopy (10.4%). There was quite low variation in the percentage of street trees although the total tree canopy was variable. These two findings can be attributed to the combination of relatively new developments and a larger number of undeveloped parcels compared to the Inner Eastside. These residential areas rarely have a well-defined right of way.

The Southwest residential areas also have a fairly low street tree contribution to the urban forest canopy (12.9%), but for different reasons than the Outer Eastside. These neighborhoods are much more heavily forested than the others, with many developments carved out of closed canopy stands. As might be expected for such an environment, street trees are a small percentage of the total canopy.

The general pattern of street trees as a component of the total canopy takes on an inverted-U shape, with higher values in the center of the map and lower values to the east and to the west. The total tree canopy category takes on just the opposite pattern – a standard-U – with the lowest values in the center of the map and the higher values to the east and west.

Industrial land exhibits a variety of spatial configurations but is, by definition, dominated by non-vegetated surfaces such as pavement and buildings. There is no consistent repeating pattern in the proportions of treed areas to other vegetation covers. In some areas, tree plantings, especially street trees, are the only vegetation. This ULE also incorporates undeveloped land, which varies from bare soil to heavily vegetated, and that vegetation is much more likely to be grass or shrub than tree. Given the extensive areas associated with this ULE, the sample unit size is probably too small for detailed analysis of this type of land cover.

Commercial properties are of two basic types: strip development along streets, and large properties such as malls with a minimal street component. For the strips, street trees are an important component. For commercial / industrial areas, unlike for residential areas, there was no apparent relationship between percentage of street trees and location within the city.

Results

This study set out to do three things:
(1) evaluate the contribution of street trees to canopy in Portland, Oregon;
(2) identify possible spatial patterns associated with the street contribution;
(3) explore some of the factors that might produce and help explain the patterns.

The analysis indicates that street trees constitute 3.4% of the whole study area. In commercial / industrial areas the figure drops down to only 1.1% and in residential areas rises to 4.8%.

For the overall study area the street tree component of the canopy is 17.2%, a figure that falls in the middle of the range of figures found in the published literature. Going a step further and considering the land cover characteristics, we found a figure of 23.7% in commercial / industrial areas and a figure is 16.6% in residential areas. Clearly we can see that in residential areas – which are overall better treed than commercial / industrial areas – street trees contribute proportionally less to overall canopy than they do in commercial / industrial areas.

In general, as the amount of non-vegetated surface increases, the percentage of street trees within the total tree canopy also increases. Logically, if there is less area in general available for planting, the right-of-way zone becomes a more significant area for planting. Conversely, more vegetation in general would mean that street trees would be a smaller component of that vegetation, since they are limited to the narrow right-of-way zones. While available planting space in the right-of-way may vary, it is much more constant than the highly variable amount of planting area available inside the block.

A related trend indicates that as non-vegetated surface area increases, the total tree canopy as a percentage of vegetation increases. Conversely, as the amount of vegetation increases in a given area, the contribution of trees becomes smaller. No trends were noted related to the percentage of street trees or tree canopy to the amount of grass / shrub in a given area.

The percentage of street trees as part of the total canopy cover varies substantially from area to area for both residential and commercial / industrial land uses, although the latter has much greater variation. The results of this relatively small sampling of the city suggest that neighborhood characteristics influence the number of street trees as a percentage of total canopy cover in a given neighborhood. A part of this influence comes from topography as factor, where steep slopes tend to limit the kind of development to residential, and to reduce the potential density to lower figures than on flatter land.

Based on numerical data and field observation experiences, the study area was divided into five residential neighborhood groups that reflect notable regional differences throughout the city. Three very generalized patterns emerge from the groupings:

1. The general pattern of street tree canopy as a percent of area seems to follow an east-west gradient, with lower values to the east and higher values to the west.

2. The general pattern of street trees as a component of the total canopy takes on an inverted-U shape, with higher values in the center of the map and lower values to the east and to the west.

3. The overall tree canopy category takes on just the opposite pattern – a standard-U – with the lowest values in the center of the map and the higher values to the east and west.

Concluding Comments

Results of this study only apply to Portland (and, in fact, only to the 77% of the city included as part of the study area). The numbers found would likely be different depending on where the boundaries were drawn and the size of the delineated areas. The regionalization is clearly somewhat subjective, highly generalized and prone to variation based on even small changes in the boundaries. However, it represents a useful starting point for understanding the dynamics of an important and highly visible component of the urban forest. Isolating the issue of street trees as a factor separate from the rest of the urban canopy adds to our understanding of the character of the urban forest and how urban forest processes operate.

Where might this research go next? Topically, the relationship of street trees to income levels, age of the neighborhood, and percent non-vegetated surface are just a few of the variables that could be explored in detail at a more local scale. The potential role of topography in street tree canopy in Portland is an avenue likely worth pursuing. Steep areas of the city tend to have higher overall percentages of canopy, but also lower densities of roads and therefore a smaller percentage of street trees.

Methodologically, a larger / more detailed sampling by residential neighborhood would allow for improved estimation of trends, perhaps below the level of neighborhood. Commercial and industrial areas could also be further evaluated following a different sampling plan from residential areas. The method of digital image interpretation used in this study is fairly labor intensive, but necessary to accurately estimate something as detailed as street tree canopy. It is also quite accurate. Delineating street trees by computer algorithm is not realistic, since simply distinguishing between grass and trees during supervised classification is difficult. Previous detailed analyses of street trees have relied upon field inventories, which are much more labor intensive than the method employed in this study. Incorporating existing field inventories of street trees into the study could supplement image interpretation, improving its accuracy and reducing its labor-intensive nature.

In terms of management, further study could focus on identifying neighborhoods that would be best served by tree planting programs, especially in the Outer Eastside. The high resolution imagery can be used to identify specific blocks within neighborhoods that could be targeted for planting (see Appendix 3 for additional comments on remote sensing issues). The results of this research could be helpful in performing comparative studies between Portland and other cities.

Street trees are defined as those trees planted in the right-of-way, either in the parking strip delineated by the sidewalk, or in the absence of a sidewalk, a similar distance from the street (usually about 6 feet but often up to 12 feet). By virtue of their being planted in the right-of-way they (in most communities) come under the jurisdiction of the city forestry program. All other trees on private property are considered yard trees and are under control of the property owner. However, it is quite common for trees planted on private property close to the street to serve as *functional street trees*, i.e., the canopy of these trees covers part of the street, serving a similar role in providing canopy as would a *definitional street tree* – one planted in the right-of-way. This thought raises an interesting management issue: If what we are concerned with is canopy over the sidewalk and street, does it really matter whether the tree stem resides in the ROW or on private property? Pondering the answer to this question may provide some food for thought on how street trees are administered and how their planting is promoted.

REFERENCES

Anderson, J. R., E. E. Hardy, J. T. Roach, & R. E. Witmer. 1976. *A Land Use and Land Cover Classification System for Use with Remote Sensor Data.* USGS Professional Paper 964; Washington, DC: USGPO.

City of Portland. 2004. *Portland Urban Forestry Management Plan.* Portland, OR.

Ebenreck, Sara. 1989. The Values of Trees; pp. 49-57 in Moll, Gary and Sara Ebenreck, eds. *Shading Our Cities.* Washington, DC: Island Press.

Grey, Gene W. and Fred J. Deneke. 1986. *Urban Forestry*, 2nd ed. New York: Wiley.

Iverson, L. R., and E. A. Cook. 2001. Urban Forest Cover of the Chicago Region and its Relation to Household Density and Income. *Urban Ecosystems* 4: 105-124.

Jensen, John R. and Dave C. Cowen. 1999. Remote Sensing of Urban and Suburban Infrastructure and Socio-Economic Attitudes. *Photogrammetric Engineering and Remote Sensing* 65(5):611-622.

Kielbaso, James J. 1990. Trends and Issues in City Forests. *Journal of Arboriculture* 16(3):69–76.

Maco, Scott E., and E. Gregory McPherson. 2002. Assessing Canopy Cover Over Streets and Sidewalks in Street Tree Populations. *Journal of Arboriculture* 28(6): 270-276.

McPherson, E. Gregory. 1993. Monitoring Urban Forest Health. *Environmental Monitoring and Assessment,* 26, 165-74.

McPherson, E. Gregory and Craig W. Johnson. 1988. A Community Forestry Planning Process: Case Study of Citizen Participation. *Landscape and Urban Planning* 15:185-94.

McPherson, E. Gregory, James R. Simpson, Paula J. Peper and Qingfu Xiao. 1999. Benefit-Cost Analysis of Modesto's Municipal Urban Forest. *Journal of Arboriculture* 25(5):235-248.

Miller, Robert W. 1997. *Urban Forestry: Planning and Managing Urban Greenspaces*, 2nd ed. Upper Saddle River, NJ: Prentice-Hall.

Moll, Gary. 1989. In Search of an Ecological Urban Landscape; pp. 13-24 in Moll, Gary and Sara Ebenreck, eds. *Shading Our Cities.* Washington, DC: Island Press.

Moll, Gary and Cheryl Kollin. 1993. A New Way to See Our City Forests. *American Forests* 99(9–10):29–31.

Moll, Gary. 1997. A Recipe for Sustainability. *American Forests* 103(3):5.

Myeong, Soojeong, David Nowak, Paul F. Hopkins, and Robert H. Brock. 2001. Urban Cover Mapping Using Digital Imagery. *Urban Ecosystems* 5:243-256.

Appendix 1: Image Data Tiles

The small pixels of the one-meter data resulted in large files, so the data were stored as five image tiles representing different flight lines and covering different sections of the city. Each tile was processed individually, resulting in five separate analysis files for the city.

Portions of the imagery outside the city were masked out of the images, as were parks and Interstate ROWs, resulting in five subsets of data files with the following sizes:

North & Northwest Portland & Forest Park	24,585 acres
Southwest Portland	10,852 acres
Downtown Portland & the inner eastside	42,591 acres
Outer eastside	32,127 acres
East Portland	3,340 acres

The sum of the tile areas is 113,495 acres (177.3 square miles), a total area that is several tens of square miles larger than the city. Although parks, interstate rights-of-way and the non-city areas around the edges of the tiles were masked out, there was substantial overlap between the tiles, and these overlap areas are included in the above tile size figures.

When selecting the 62 sample patches, they were distributed among the five image tiles in proportion to the city area covered by that image tile.

Since reflectance values varied somewhat between the five image tiles, each was classified separately. Between 12 and 16 training sites were applied to each image tile. The results of the final classification are summarized in Figure 9.

Although the image tiles were analyzed separately, the samples were pooled to produce a composite accuracy assessment for the five image classifications. Random pixels were selected for each of the five image tiles and the accuracy of the digital classification determined by visual interpretation. The results are presented in Figure 10.

Appendix 2: Sample Patch Data

(page 1 of 2)

Residential Sample Patches

ID	Neighborhood	Cross Streets	Area	Area - in pixels						STC - %	Description / Notes
				Street Trees	Non-Street Trees	Total Trees	Grass	Total Vegetated	Non-Vegetated		
1_15	St. Johns	N Kellogg/ St. Johns	NE	1,475	4,444	5,919	12,978	18,897	21,103	24.9	grid
3_10	King	NE 8th/Skidmore	NE	3,288	4,760	8,048	9,749	17,797	22,203	40.9	grid
3_11	Beaumont- Wilshire	NE 35th/Siskiyou	NE	3,019	6,485	9,504	10,490	19,994	20,006	31.8	mix of grid and winding streets
3_12	Cully	NE 50th Pl/Going	NE	1,214	10,800	12,014	10,351	22,365	17,635	10.1	grid- dead end streets- no sidewalks
3_13	Cully	NE Prescott	NE	797	8,714	9,511	12,864	22,375	17,625	8.4	grid- no cross streets- sidewalk on arterial
3_14	Concordia	NE 34th/Ainsworth	NE	3,020	5,807	8,827	12,106	20,933	19,067	34.2	grid
3_15	Cully	NE 52nd/Simpson	NE	1,106	6,726	7,832	12,831	20,663	19,337	14.1	grid- dead end streets- no sidewalks
3_16	Sullivan's Gulch	NE 19th/ Clackamas	NE	2,765	7,292	10,057	6,384	16,441	23,559	27.5	grid
3_9	Kenton	N Hunt/Endicott	NE	549	7,486	8,035	10,572	18,607	21,393	6.8	grid
4_13	Rose City Park	NE 53rd/Siskiyou	NE	2,178	2,911	5,089	10,163	15,252	24,748	42.8	grid
4_14	Rose City Park	NE 60th/Tillamook	NE	2,515	9,631	12,146	8,390	20,536	19,464	20.7	grid
3_17	Mt. Tabor	SE 57th	SE	693	9,274	9,967	8,551	18,518	21,482	7.0	grid- no cross streets
3_19	Creston-Kenilworth	SE 33rd/Francis	SE	791	6,816	7,607	8,318	15,925	24,075	10.4	grid
3_20	Creston-Kenilworth	SE 50th/Cora	SE	2,322	5,019	7,341	9,653	16,994	23,006	31.6	grid
3_22	Sellwood	SE 17th/Lambert	SE	1,799	6,574	8,373	7,218	15,591	24,409	21.5	grid
3_23	Brentwood/ Darlington	SE 48th/Ogden	SE	1,368	5,003	6,371	9,649	16,020	23,980	21.5	grid
3_25	Sellwood	SE 16th/Marion	SE	3,263	6,748	10,011	9,044	19,055	20,945	32.6	grid
3_30	Buckman	SE 37th/Taylor	SE	5,464	8,676	14,140	6,088	20,228	19,772	38.6	grid
3_31	Center/Mt. Tabor	NE 65th/Burnside	SE	1,661	7,675	9,336	10,691	20,027	19,973	17.8	grid
4_4	Montavilla	NE 72nd/Pacific	SE	747	4,071	4,818	7,858	12,676	27,324	15.5	grid- half of area is school
4_8	Lents-Powellhurst-Gilbert	SE 108th/ Mitchell	OE	886	8,572	9,458	14,115	23,573	16,427	9.4	large properties with undeveloped land- no sidewalks
4_9	Powellhurst-Gilbert	SE Steele	OE	1,547	9,201	10,748	15,623	26,371	13,629	14.4	one street- several dead ends- no sidewalks
5_1	Wilkes	NE 162nd/Fargo	OE	1,818	11,940	13,758	5,006	18,764	21,236	13.2	includes apartment complex, new construction and undeveloped land
2_1	Hillsdale	SW Seymour	SW	1,885	18,970	20,855	8,870	29,725	10,275	9.0	winding streets- includes ~40% undeveloped land- no sidewalks
2_2	Hayhurst	Cullen / SW 39th	SW	3,204	21,399	24,603	4,838	29,441	10,559	13.0	winding streets- includes undeveloped land- no sidewalks
2_3	Hayhurst	Illinois/SW 30th	SW	3,409	13,471	16,880	7,072	23,952	16,048	20.2	grid- no sidewalks
2_4	Multnomah	Texas/SW 28th	SW	2,856	12,147	15,003	6,696	21,699	18,301	19.0	grid- includes church and undeveloped land- no sidewalks
2_5	Ash Creek	Garden Home/ SW 52nd	SW	3,475	18,384	21,859	7,823	29,682	10,318	15.9	mix of grid and winding streets- large properties- no sidewalks
2_6	Multnomah	Multnomah / SW 25th	SW	2,253	6,158	8,411	5,534	13,945	26,055	26.8	includes school- no sidewalks
2_7	Markham	Marigold / SW 19th	SW	2,112	14,054	16,166	8,062	24,228	15,772	13.1	grid- no sidewalks
3_24	Marshall Park	SW 8th Dr	SW	1,938	20,551	22,489	8,717	31,206	8,794	8.6	winding streets- includes ~30% undeveloped land- no sidewalks
3_32	Marshall Park	SW 14th Dr / Kari Ln	SW	698	22,572	23,270	6,248	29,518	10,482	3.0	winding streets- large lots- no sidewalks

Appendix 2: Sample Patch Data
(page 2 of 2)

Commercial / Industrial Sample Patches

Sample	Neighborhood	Cross Streets	AREA - Pixels				STC - %	Description / Notes
			Street Trees	Total Trees	Vegetated	Non-Vegetated		
1_1	St. Johns	None	-	-	-	40,000		open space- no trees
1_2	St. Johns	None	522	651	3,016	36,984	80.2	industrial- riverside
1_3	St. Johns	N Ramsey	68	335	4,282	35,718	20.3	industrial- includes only part of one street
1_5	St. Johns	None	-	-	896	39,104		industrial parking area- no trees
1_14	St. Johns	N Marine Dr/ Leadbetter	102	241	1,461	38,539	42.3	industrial- half undeveloped with road intersection
3_18	Reed	SE 24th/Pardee	-	-	-	40,000		no trees
3_26	Northwest District	NW 22nd/ Lovejoy	2,564	3,043	7,489	32,511	84.3	commercial strip- most of sample area is a hospital but zoned residential
3_27	Eliot	N Ross/Page	579	1,110	3,224	36,776	52.2	industrial
3_28	Lloyd District		217	827	2,892	37,108	26.2	Rose Garden
3_29	Hollywood	NE 44th/Sandy	1,614	2,233	6,119	33,881	72.3	commercial strip- includes ~10% residential
3_4	Kenton	Expo TC	1,736	4,737	7,245	32,755	36.6	mostly undeveloped
3_5	Airport	None	-	-	39,939	61		open space- no trees
3_6	Airport	None	-	-	-	40,000		no trees
3_7	Airport	None	-	-	5,438	34,562		no trees
3_8	Kenton	N Wilbur/ Newark	37	217	643	39,357	17.1	industrial- one street- few trees
4_15	Parkrose Heights/ Hazelwood	NE 118th/ Halsey	355	866	X	X	41.0	commercial strip- includes ~30% residential
4_16	Russell	NE 122nd	336	1,603	1,156	38,844	21.0	commercial
4_19	Powellhurst- Gilbert	Unnamed roads	-	12,457	25,987	14,013	0.0	mostly open space- no street trees
4_2	Airport	NE Cascades Pkwy	1,685	2,645	27,524	12,476	63.7	industrial- mostly undeveloped- one road with trees
4_20	South Tabor	SE 67th/Powell	1,085	1,725	X	X	62.9	commercial strip- most of area is residential
4_21	Cully	NE Skyport Wy	511	9,202	17,642	22,358	5.6	industrial- includes portion of Columbia Slough and open space- only part of one street
4_22	Airport	Perimeter Rd	-	-	21,271	18,729		mostly open space- no trees
4_3	Airport	Perimeter Rd	-	-	17,522	22,478		mostly undeveloped- no trees
4_5	Argay	NE 148th	-	2,683	10,306	29,694	0.0	industrial- no roads- mostly undeveloped
5_2	Centennial	SE 174th/Division	871	1,753	X	X	49.7	commercial strip- includes ~20% residential

Appendix 3: Remote Sensing Issues

Although the use of high spatial resolution imagery is necessary for the type of detailed analysis this project entailed, there are a number of challenges inherent in the use of high-spatial resolution imagery (compared with moderate or low-resolution imagery) for land use classification. The complex heterogeneous nature of the urban environment is a problem for classification processes in general, but even more so at one-meter resolution. A large number of edges and mixels / mixed-pixels are inevitable, especially along the many changes between vegetated and non-vegetated areas. Although post-classification filtering can be used to decrease the misclassification that results from the high number of edges, those processes were not applicable to the detailed nature of this study. Identifying isolated and small groups of pixels of a distinct and different class was the goal and these “salt and pepper” effects could not to be removed.

The number of pixels corresponding to an individual tree often numbers in the single digits. The resulting preponderance of edges leads to misclassification of individual pixels. However, each sample patch was comprised of 40,000 pixels, and the classification exhibits improved accuracy over this larger area as errors of commission tend to balance errors of omission. For example, some grass areas are classified as deciduous trees and increase canopy cover. However, some types of deciduous tree have signatures coincident with grass and are not counted as part of the canopy.

The same kind of balance is found in shadow areas. In high resolution imagery, shadow effects are pronounced. Compared with lower resolution satellite images where the shadows comprise a small percentage of any given pixel, high resolution imagery will have many individual pixels completely encompassed by shade. The shadow areas for buildings conflate with the signatures for conifer trees, and this tends to increase canopy cover. On the other hand, shadowed portions of deciduous tree canopy may be misclassified as non-vegetated surface and not counted as part of the canopy.

Part of what allowed this study to be performed was the availability of one-meter resolution digital remote sensing data. Ten years ago such data was virtually non-existent and processing it in a reasonable timeframe would require a specialized computer system. Ten years from now it is possible that one-meter data will be considered medium resolution or at least be superceded by “hyper-resolution” data measured in single-digit (or perhaps even decimal) inches. Computing power will likely allow even faster processing of the necessarily larger “hyper-resolution” data sets than technology allows today with relatively smaller data sets. This study is thus not definitive from a remote sensing viewpoint, but instead represents the current state-of-the-art of a rapidly-evolving technology.